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Research paper

Assessment of different feedstocks in South Tyrol (Northern Italy): Energy potential and suitability for domestic pellet boilers

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A B S T R A C T

The present study aims to quantify the main biomass resources in South Tyrol (Northern Italy) and estimate the potential contribution for the energy sector. Moreover, four representative feedstocks have been tested in a domestic pellet boiler under standard conditions in order to assess its performance and pollutant emissions.

The unexploited biomass potential for energy conversion applications, expressed as dry weight, has been estimated to be 135 000 t y^{-1} from forest, 14 950 t y^{-1} for apple pruning residues and 12 000 t y^{-1} from the industrial sector. The scenario of utilizing the unexploited local biomass resources – in energy systems such as the ones deployed in South Tyrol – would contribute with an annual bioenergy production contribution of 130–270 TJ of electricity and 1700–2100 TJ of heat. Finally, the tested feedstocks can be used in domestic boilers, however, some modifications are required when using agricultural residues.

1. Introduction

In the last years, the production of energy from renewable sources is increasing and biomass is considered as an energy source with a great potential. On a global scale, biomass contributes to the supply of energy with a share between 10 and 14% [1]. Green policies for the promotion of energy from renewable sources have been developed all around the world. In particular, the European Union (EU) set the climate and energy package known as "20-20-20" targets in which the directive 2009/28/EC promotes the use of energy from renewable sources with the aim to raise the green energy share to 20% by 2020.

On this basis, studies are increasingly carried out with the aim of estimating the amount of biomass that could be used as energy source. In particular, agricultural residues achieve considerable interest due to the compliance to the cascade principle (i.e. biomass utilization with the following order of priority: wood-based products, re-use, recycling, bioenergy and disposal). In accordance with the literature review, the agricultural biomass potential in the EU by 2020 is between 0.73 EJ y^{-1} and 1.43 EJ y^{-1} [2]. The wide range of estimations is due to different calculation techniques, different parameters as sustainability indicators, economic aspects, local conditions and legislation of the considered countries [3–5]. A study carried out in Mediterranean areas reports a quantification of the available residual biomass obtained from pruning olive trees. It has been estimated, on average, 1.31 t ha^{-1} in annual pruning and 3.02 t ha^{-1} in biennial pruning that could be used as a source of energy [6].

With regard to riparian biomass, Tiefenbacher [7] performed a precursor study on short rotation forestry for energy production in Austria that involved some of the most widespread riparian tree species. Aosar et al. [8] have investigated the biomass production potential of grey alder (*Alnus incana*) forests in Scandinavia and Eastern Europe, stating a mean annual increment in dry matter for 20-year-old stands comprised between 2.56 m^3 ha^{-1} and 4.75 m^3 ha^{-1}. Studies conducted on mixed riparian forests in Northern and Central Italy [9,10], assess the total amount of biomass derived from riverbank management operations in the range of 50–70 t ha^{-1}, but up to 180 t ha^{-1}. A case study carried out in Central Italy presents an operational methodology for investigating the biomass potential from riparian forests by coupling airborne laser scanning data with a field survey. It highlights an average aboveground lignocellulosic biomass of about 90 t ha^{-1} (800 t km^{-1} of river length) in poplar-dominated forest [11]. In Italy,

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riparian forests cover roughly 1% of the national land area (i.e. 3000 km^2) and are characterised (on average) by 60 t ha^{-1} of lignocellulosic biomass [12]. These amounts, although not comparable to those derivable from specialized plantations for biomass production, may constitute a complementary contribution to the renewable energy production, but within environmentally sound river management plans.

Biomass for energy conversion is usually considered as a resource for local utilisation, however, it can be exported to other regions. In the latter case, the bioenergy transport chains can create additional logistics, costs, energy consumption and material losses compared to the local utilisation [13,14].

Besides the assessment of the biomass energy potential, several studies discuss the suitability of lignocellulosic and non-lignocellulosic biomass for energy production. Carvalho et al. [15] investigate several agricultural fuels highlighting a higher fouling of the heat exchanger due to a high ash content. The pollutant emissions were higher compared to the ones obtained with lignocellulosic biomass, however, the agricultural feedstocks satisfied the limits defined in the EN 303-5 [16] with the exception of straw and *Sorghum* regarding particulate emissions. Verma et al. [17] confirm the critical behaviour of straw, in particular due to the high ash content and low melting point. Moreover, straw pellets emitted the highest NO_x and SO_x emissions among several agro-pellets. Winter et al. [18] denoted the high rate of conversion to NO from agricultural waste combustion along with several other minor compounds, mainly HCN, NH_3, and N_2O. Picchi et al. [19] carried out a comparison between vineyard residues and spruce. The main outcomes show high CO emissions for vineyard residues that could be tackled with some modification to design and settings of the boiler. Moreover, the authors stated that agrochemicals – used for the treatment of the plants – are not significantly increasing the heavy metal emissions released during biomass combustion. Serrano et al. [20] and Carvalho et al. [15] emphasized the importance of proper settings of the boiler, in accordance with the characteristics of the fuel, in order to reduce the pollutant emissions. In support of this argument, Li et al. [21] stated that an additional influencing factor for the formation of CO and NO is the position of the burning zone with respect to the inlet of the boiler.

In South Tyrol (corresponding to the Autonomous Province of Bozen-Bolzano, Northern Italy), a large share of forest biomass is already used for energy purpose, however, a further share could be exploited. In 2009, roughly 180 TJ of electricity and 2500 TJ of heat were generated by combined heat and power (CHP) system fed by lignocellulosic biomass and an additional share of 3000 TJ of heat was produced by small-scale boiler distributed on the territory [22].

The present study aims to assess the unexploited energy potential of the Province's main biomass resources. Forest biomass potential has been calculated considering the environmental, management and economic constraints in South Tyrol. The agricultural biomass – i.e. lignocellulosic residues of apple orchards – has been quantified through field measurements. For the estimation of the biomass, that could be derived from riparian vegetation, a methodology coupling Airborne LiDAR data with field sampling plots has been applied. Industry biomass, mainly from sawmills, has been assessed on the basis of some studies carried out in the north-east of Italy. Finally, four different feedstocks (i.e. Norway spruce, willow, apple logs and apple prunings) – representative of the sectors (i.e. forest, riparian vegetation, agriculture, timber industry) in which the potential assessment has been carried out – have been tested in a domestic pellet boiler in order to assess its performance and pollutant emissions. In addition, heat and power potential of the unexploited biomass has been estimated on the basis of the possible biomass-to-energy systems present in South-Tyrol.

2. Material and methods

2.1. Biomass quantification in South Tyrol

2.1.1. Forest sector assessment

The territory of the Autonomous Province of Bolzano (7400 km^2) is mountainous, with more than 40% of the entire surface lying above 2000 m above sea level. As shown in Fig. 1, forests cover about 50% of the entire surface (i.e. 372 174 ha) and 90% of this area is covered by "high forest" (i.e. forest originated from seeds) [24]. The distribution of the main tree species accounts for 61% of Norway spruce (*Picea abies*), 19% of European larch (*Larix decidua*), 10% of Scots pine (*Pinus sylvestris*) and Black pine (*Pinus nigra*), 6% of Cembran pine (*Pinus cembra*), 3% of European silver fir (*Abies alba*) and 1% of European beech (*Fagus sylvatica*) [24]. Currently, in South Tyrol about 865 dam^3 y^{-1} of biomass – considering stem, branches and tops – are harvested every year. 75% of such volume has commercial purpose as timber (55%) and firewood (20%), while the remaining 25% are branches and tops. The present forest management plans foresee that branches and crown tops have to be left at the harvesting site.

The assessment of the forest-biomass potential has been performed taking into account indices and coefficients from literature, as well as management guidelines suggested by the Forest Department of the Autonomous Province of Bozen-Bolzano. The assessment is based on a sustainable forest management approach considering the net annual increment (NAI) – values reported on the second National Forest Inventory for every main tree species – as the maximum sustainable limit of harvesting wood per year [25]. For the forest in South-Tyrol, the average value of NAI corresponds to 5.5 m^3 ha^{-1} [12]. Therefore, if only the increment is harvested every year, forest degradation does not occur [26]. The potential biomass assessment has taken into account the volume of the stem as well as the branches for the entire forest surface. For every tree species, the net annual increment has been multiplied by the Biomass Expansion Factors (BEF) and by the respective surface. The BEF index is a specific multiplying factor for every tree species which takes into account the volume of branches and tops in relation to the net annual increment [27,28]. Therefore, using NAI and BEF indices, it has been possible to estimate the total annual biomass – stem and branches and crown tops – available from the forest.

For the estimation of the sustainable amount of biomass harvestable in the Province, the total volume has been adapted considering the environmental and operational constraints. A certain amount of biomass has to be released *in loco* in order to ensure the soil protection function of the forest [29], soil fertility [30] and the protection of the site's biodiversity [31]. According to the local forest management guidelines, for those forests with protection aims, the amount of harvestable biomass is respectively decreased from 5.5 m^3 ha^{-1} – average NAI present in the second National Forest Inventory – to 2 m^3 ha^{-1} (i.e. a decrement that ensures a sufficient forest density) and 4.5 m^3 ha^{-1} (i.e. a decrement that ensures a good stock of juvenile plants) [29].

The amount of biomass (branches and tops) that should be released on site, in order to avoid the removal of nutrient elements to maintain soil fertility, has been calculated in accordance with the guidelines proposed by the EEA [30]. Masutti and Battisti [31] suggest to release a minimum amount of dead wood of 15 m^3 ha^{-1} in order to maintain a high biodiversity. Currently, the average amount of deadwood present in the forest is 12.4 m^3 ha^{-1} [32], therefore the missing difference to reach the values suggested by Masutti and Battisti has been considered in the analysis.

The most common harvesting system in the Province of Bolzano is the cable logging (maximum logging distance of 800 m) [24].